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BRL

COMBUSTIBLE METALLIC IGNITER CASING FOR TANK GUNS

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NOVEMBER 1991

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Calculations have shown that a combustible metallic igniter casing for tank cannon can be made to withstand the pressure loads created by combustion of the igniter charge, yet - when consumed by the flame of the main charge - not adversely elevate the maximum chamber pressure at any position. In particular, a finite-element model, I-DEAS, was used to evaluate the structural response of various combustible igniter casings when subjected to internal pressure loads imposed by the combustion of the igniter charge. A state-of-the-art interior ballistics code, XNOVAKTC, was used to evaluate the effect which combustion of the interior casing itself has on maximum chamber pressures and projectile launch velocity. Initial tests have been reasonably successful, both in demonstrating the feasibility of the concept and in yielding results not unlike those predicted from the models.

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I. Introduction

Conventional tank gun ammunition is configured with the propellant igniter along the central axis of the propellant bed, see Fig. 1a. The igniter is a perforated steel tube which extends from the primer "head", located in the center of the cartridge stub base, to the base of the projectile. The propellant is ignited through a series of events which begins when the firing key is closed and a small electric current is passed through a resistive heating element in the primer "head." This ignites a small powder charge which vents its flame into, and ignites, the charge contained within the igniter tube. The flame from the igniter charge combustion is vented through the igniter tube perforations and into the propellant, which begins to burn roughly 2-7 *ms* after the close of the firing key.

For 105-mm ammunition the igniter tube is ejected along with the surrounding, non-combustible, metal cartridge side-wall. Since the side-wall extends well beyond the igniter, there is no space-savings to be gained from a combustible igniter casing. Moreover, the side-wall shields personnel and unfired ammunition from coming in contact with the hot, post-fired igniter tube.

However, with the advent of 120-mm ammunition the combustible cartridge case side-walls are consumed along with the propellant, leaving the igniter tube protruding from the "stub" base upon ejection. Though space-savings is gained, special care must now be taken to prevent the hot, post-fired igniter tube from contact with personnel, or — more seriously — from contact with the combustible side-wall of the next round to be loaded.

In addition, the length which the igniter tube adds to the ejected base contributes to the design complexity of future auto-unload systems. A combustible igniter tube would alleviate these problems. Furthermore, with the minimal space requirements of the casing stub base alone, it may be possible to store all post-fired components of the ammunition on board without opening the crew compartment (to a potentially hazardous NBC, Nuclear-Biological-Chemical, environment) to discard the casings, as is the current procedure.

This paper discusses several combustible metallic, high-pressure, igniter tube designs. The combustible metals examined are aluminum and magnesium, both of which can ignite and burn in the gun chamber, as will be shown here (and indicated in previous studies, Davis,[1] Bundy et al.[2]). Finite-element modeling, using I-DEAS software,[3] is employed to evaluate the minimum wall thickness necessary to contain the pressure pulse created by the igniter charge. Interior ballistics modeling, using XNOVAKTC[4] (XKTC, a two-phase, one-dimensional (with area change), interior ballistics computer code), is utilized to investigate the effect which the exothermic igniter oxidation has on the overall performance of the ammunition. The results of preliminary experiments will be discussed and future plans will be disclosed.

[1] Davis, D.M., "Historical Development Summary of Automatic Cannon Caliber Ammunition: 20-30 Millimeters," AFATL-TR-84-03, Air Force Armament Laboratory, Eglin Air Force Base, Florida, January 1984.

[2] Bundy, M.L., Horst, A.W., Robbins, F.W., "Effects of In-Bore Heating on Projectile Fins," BRL-TR-3106, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1990.

[3] "I-DEAS User's Guide", for I-DEAS finite-element software, Structural Dynamics Research Corp., Milford, Ohio, 1990.

[4] Gough, P.S., "The NOVA Code: A User's Manual," Indian Head Contract Report No. 80-8, Naval Ordnance Station, Indian Head, MD, December 1980.

II. Finite-Element Modeling (FEM)

Three igniter tube designs were examined using the I-DEAS finite-element structural analysis program. The program predicts the structural response of physical objects, or structures, subjected to statically applied forces. The response will vary linearly with the applied load. Displacements, stresses and reaction forces are some of the data which can be obtained.

Each igniter tube was modeled as being 29 *cm* long, with twelve 4.8 *mm* diameter holes drilled through the tube, spaced 19.1 *mm* apart, at 90 degree intervals. The outer diameter of each tube was 17.5 *mm*. There was a "thick-walled" aluminum tube with a wall thickness of 2.2 *mm*, and a magnesium tube with the same wall thickness. There was also a "thin-walled" aluminum tube with a wall thickness of 0.8 *mm*.

The igniter tubes were modeled using quadrilateral thin shell elements centered at the mid-surface of the tube wall, see Fig. 1b. Each element was assigned a physical thickness equal to the wall thickness. Isotropic material properties for modulus of elasticity, Poisson's ratio and density were defined. For simplicity, the pressure load during the igniter charge combustion was assumed constant at a value near its maximum; specifically, a pressure of 21 MPa ($\approx$3 $kpsi$) was applied to the internal faces of the thin shell elements. The tube was held fixed at the bottom of the model (right-hand-side in Fig. 1b) where it would (physically) screw into the primer head.

The von Mises stress values were obtained for the outer, middle and inner surfaces of the walls. (Von Mises stress is not a typical stress in the sense that it represents a force per unit area relative to any particular surface. Rather, it is proportional to the magnitude of a particular combination of the principle stresses; such that, the von Mises stress squared divided by the shear modulus is proportional to the energy density stored in the form of shear deformation. As a result, if the von Mises stress at any point in a body, which is being subjected to a complex (multi-axial) stress load, is more than the (tabulated) yield stress from a simple (uni-axial) tension test, then the material can be expected to fail at that point under the complex load due to excessive shear energy density.)

Under the imposed internal pressure load, the highest stress areas occur on the inside surface along a line parallel to the axis of the tube and bisecting the holes. The maximum stress is concentrated along this line in an area less than one hole diameter wide on either side of the vent holes, see (for example) Fig. 2a,b.

For the thick-walled aluminum tube, the maximum static stress is predicted to be 248 MPa (36 $kpsi$), which is below its static yield (0.2 % offset) strength of 482 MPa (70 $kpsi$). (In actuality, since the dynamic yield strength is always higher than the static yield strength, such a static strength comparison produces a conservative assessment of possible igniter casing failure.) For the thin-walled aluminum tube, a high stress of 972 MPa (141 $kpsi$) occurs around the holes on the inner surface (Fig. 2b), which exceeds its tensile (rupture) strength of 572 MPa (83 $kpsi$). However, at the mid-surface, the high stress has dropped to 537 MPa (78 $kpsi$); and at the outer surface, the maximum stress is only 406 MPa (59 $kpsi$). This distribution of stress indicates that localized failure may occur around the holes from the inside out. But, since the bulk of the material between the holes is stressed

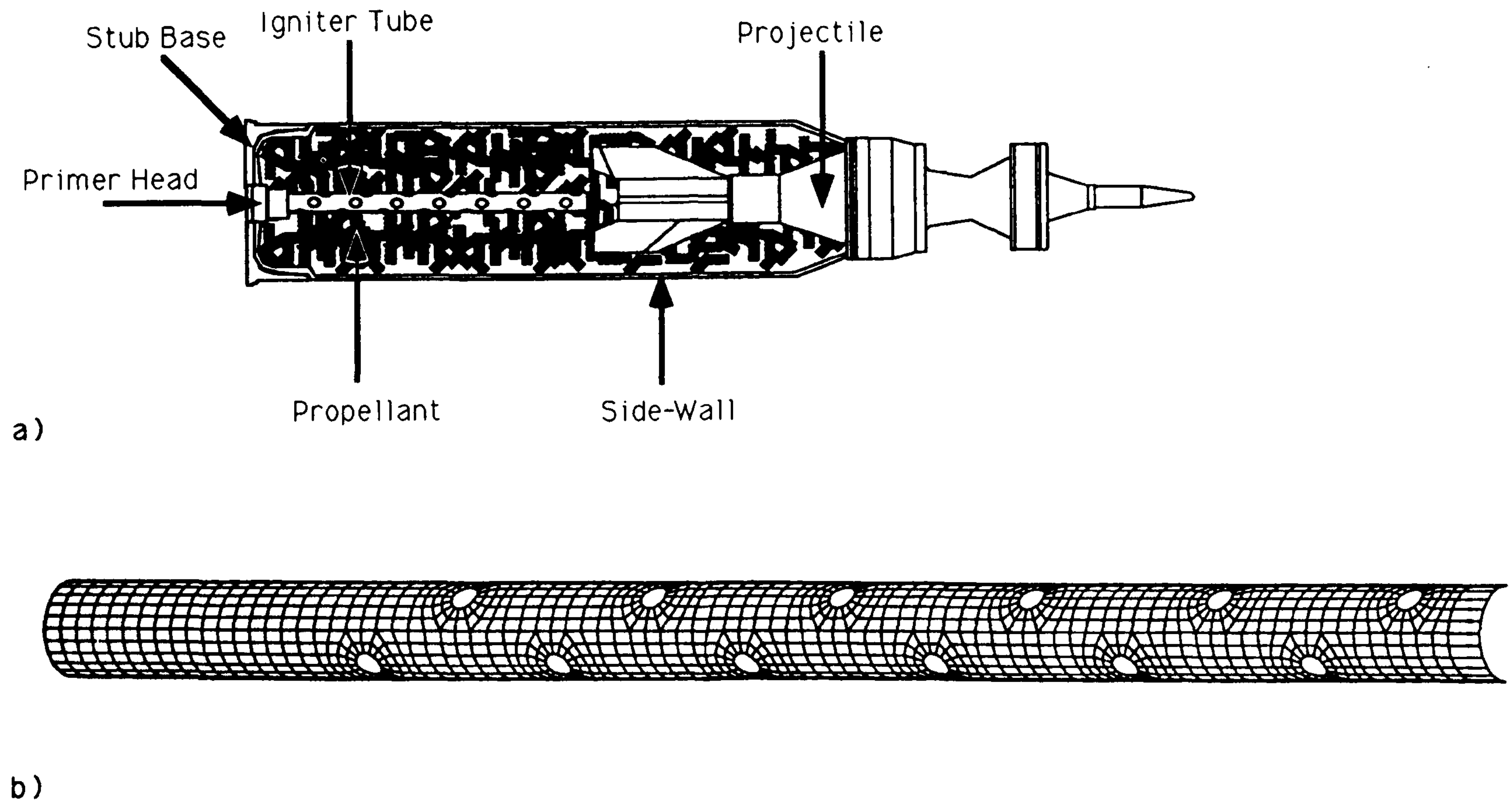

Figure 1. a) Schematic of Generic Tank Gun Cartridge Case; b) FEM Grid (Using Thin Shell Elements) for Igniter Tube

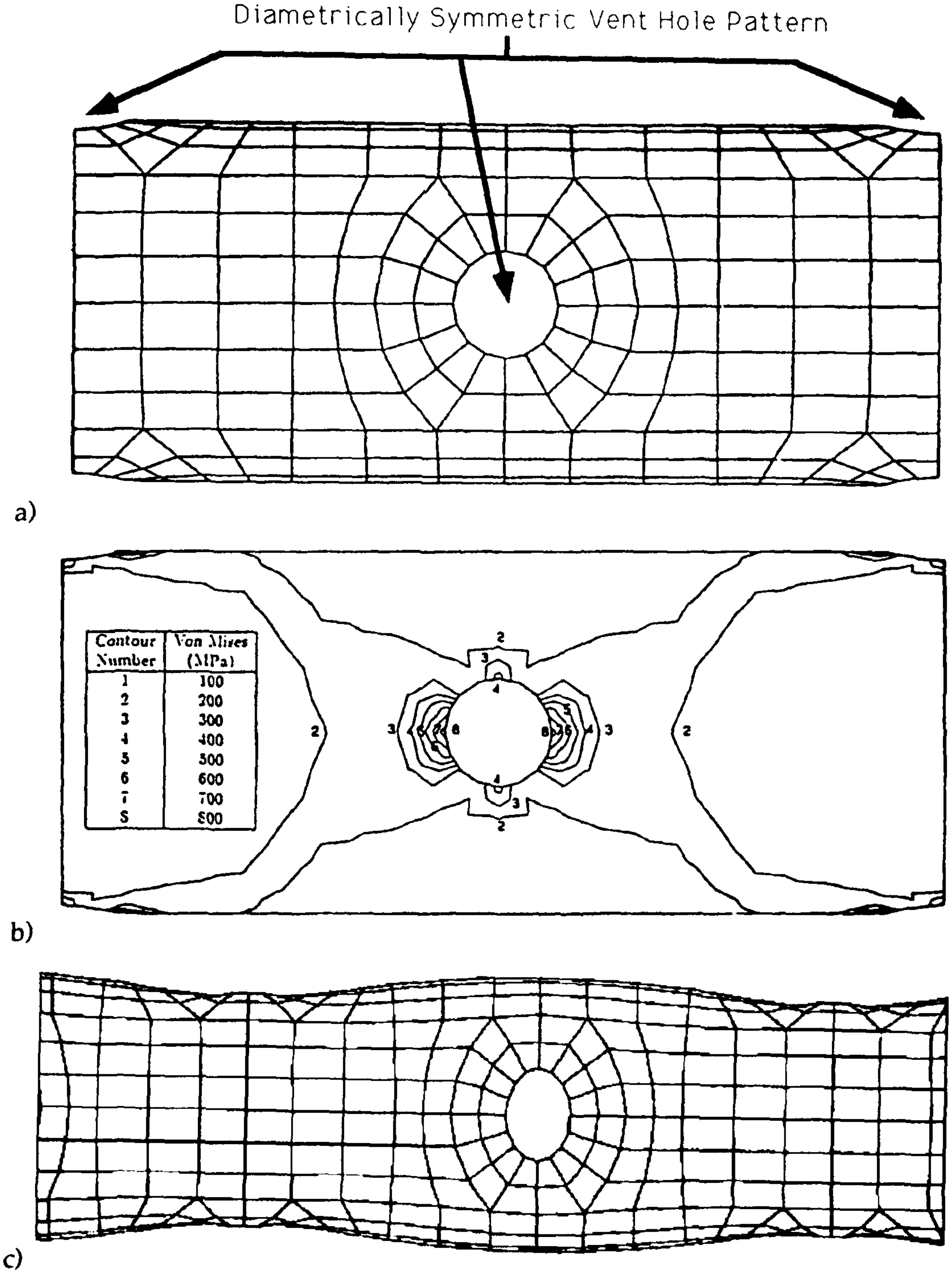

Figure 2. a) Local FEM Grid Around Igniter Vent Hole, b) Region of Maximum Stress (Due to Igniter Charge Combustion) in Thin Aluminum Casing (Located Around Inner Surface of Vent Hole), c) Deformation (Mag.=20x) Caused by Stress Level in Fig. 2b

below 241 MPa (35 $kpsi$), the structural integrity of the tube – as a whole – is assured. The deformation caused by the stress levels shown in Fig. 2b, is displayed in Fig. 2c. Note, the maximum outward bulge in the casing is symmetrically located between holes. Or, conversely, the minimum outward bulge is located in the vicinity of the vent holes. This is to be expected, since the presence of a vent hole, as opposed to the absence of a vent hole, in the casing reduces the local surface area and hence the local outward force resulting from the internal pressure rise.

Since the magnesium tube had the same geometry as the thick-walled aluminum tube, the stress distributions are identical. The yield strength of the magnesium is roughly 240-275 MPa (35-40 $kpsi$), and since the static yeild strength will be lower than the dynamic yield strength, the magnesium igniter will probably not fail mechanically during the ignition process.

In summary, FEM predictions indicate that all three designs are structurally adequate to withstand the internal pressure generated during the igniter charge combustion process. Damage – if any – should be limited to material yield at the inner wall edge of the igniter vent holes on the the magnesium and the thin-walled aluminum designs only.

III. Interior Ballistics Modeling

The standard steel igniter tube is 29 cm long and and 17.6 mm in diameter, with a mass of 189 *grams* (excluding the igniter charge). It was assumed, for modeling purposes, that an aluminum igniter would have a mass of 50 *grams* uniformly distributed over the same length and diameter as the standard igniter.

The products formed, and the energy liberated, by the combustion of one part aluminum and nine parts JA2 propellant were evaluated using BLAKE, an equilibrium thermochemistry computer code.[5] It was determined that 5000 J/g of energy would be released in the burning process. This energy release density, along with the assumption of a 1200 K ignition temperature, and a "burning rate" given by "ap^n" with $n = 1$ and a varied so as to consume the igniter in 0.3, 1.0 and 3.0 ms, were used as input to the XKTC model.

Note, the assumption of a 1200 K ignition temperature for aluminum is roughly one-half the typical value quoted (e.g., Ref. 6). This is done to compensate for XKTC's one-dimensional analysis of the surface heat transfer in critical areas where the exposed surface is two- or three- dimensional, such as around the edge of the igniter vent holes, where the onset of aluminum ignition is believed to occur. Furthermore, not knowning how long it would take to consume the combustible igniter, calculations were performed over an order of magnitude spread in the burning rate.

[5]Freedman, E., "BLAKE - A Thermodynamic Code Based on TIGER: User's Guide and Manual," ARBRL-TR-02411, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1989.

[6]Friedman, R. and Maček, A., "Combustion Studies of Single Aluminum Particles," *9th International Symposium on Combustion*, 1963, pp. 703-712.

In the worst case, the calculations indicated that the maximum pressure would be increased by 10-15 MPa and that little or no effect would be seen on the muzzle velocity or on wave dynamics (as characterized by pressure difference curves). This prediction was, in fact, consistent with experiment, as discussed next.

IV. Experimental Observations

Three igniter tube designs were fabricated as dimensioned in the FEM section: two from 7075-T6 aluminum and one from magnesium. To increase the surface area, a v-shaped groove was machined into the outer-wall of each tube (12.6 grooves per cm with a 0.5 mm groove depth), see schematic in Fig. 3. The thickness of the tube from the inner wall radius to the minor radius of the groove was the same as that modeled in the FEM section. The thicker aluminum tube had a mass of 88 *grams*, while the thinner aluminum tube had a mass of 50 *grams*. The mass of the magnesium tube was 58.5 *grams*.

The (steel) igniter-train assembly, consisting of the primer head and igniter tube, was removed from three German DM13 120-mm kinetic energy (KE) rounds. The igniter tubes were unscrewed from the primer heads; the charge removed; and the combustible (replacement) casings re-threaded into the primer heads. Then, the igniter charge was reloaded into the combustible casings and the igniter-train assemblies reinserted into the rounds. The rounds were then ready to be fired.

The gun firings were conducted at the Sandy Point Firing Facility (Range 18), located at the Ballistic Research Laboratory (BRL), Aberdeen Proving Ground, Maryland. A standard 120-mm M256 gun tube was instrumented with five pressure gages along the chamber length: two at 0.095 m, one at 0.286 m, and two at 0.489 m from the rear face of the tube. There were also six gages down the bore: one each at 0.786 m, 1.048 m, 1.530 m, 3.054 m, 3.816 m, and 4.578 m from the rear face of the tube. The velocity was measured with a 10.5 GHz Weibel down-range Doppler radar system. All charges were temperature conditioned to 294 K.

The post-fired casings, consisting of the stub base and the remains of the igniter tube, are shown in Fig. 4. Figure 4a is the baseline (steel) igniter, unaffected by the gun firing. The thick-walled aluminum igniter was roughly half-burned, Fig. 4b; while the thin-walled aluminum igniter was 90% burned, Fig. 4c, and the magnesium was almost totally burned, Fig. 4d.

The pressure-versus-time curves at 0.095 m, 0.489 m, 0.768 m, 1.530 m, 3.054 m, 3.816 m, and 4.578 m for the baseline DM13 gun firing are given in Fig. 5a. The corresponding pressure-versus-time curves for the thick aluminum igniter casing, thin aluminum casing and the magnesium casing are given in Figs. 5b-d.

Pressure difference curves are the curves generated when the pressure at the front end of the gun chamber is subtracted from the pressure at the breech end of the gun chamber. The pressure difference curve would have large (greater than 35 MPa) negative values for charges which have potentially deleterious pressure waves generated during the early portion of the ballistic cycle. The pressure difference curves for the baseline DM13 and the rounds with different igniter casing material are given in Fig. 6. As can be seen the pressure difference

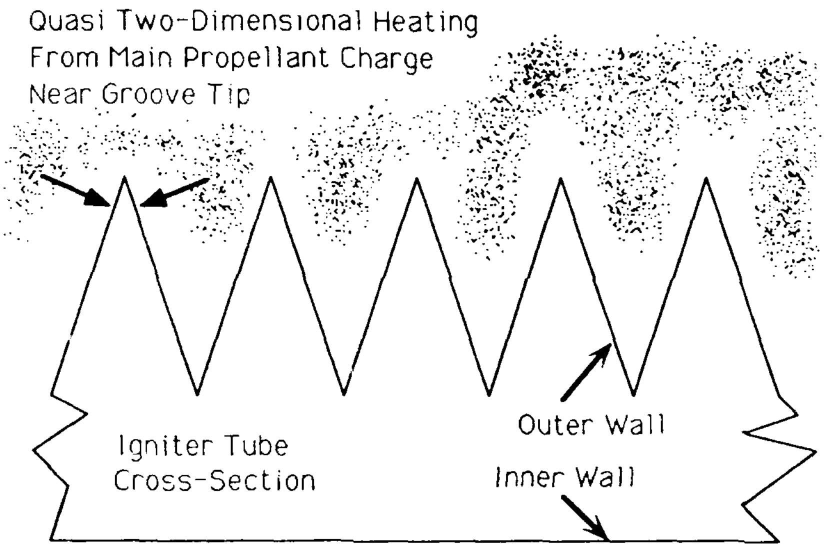

Figure 3. Schematic of Igniter Tube Cross-Section with V-Groove Pattern

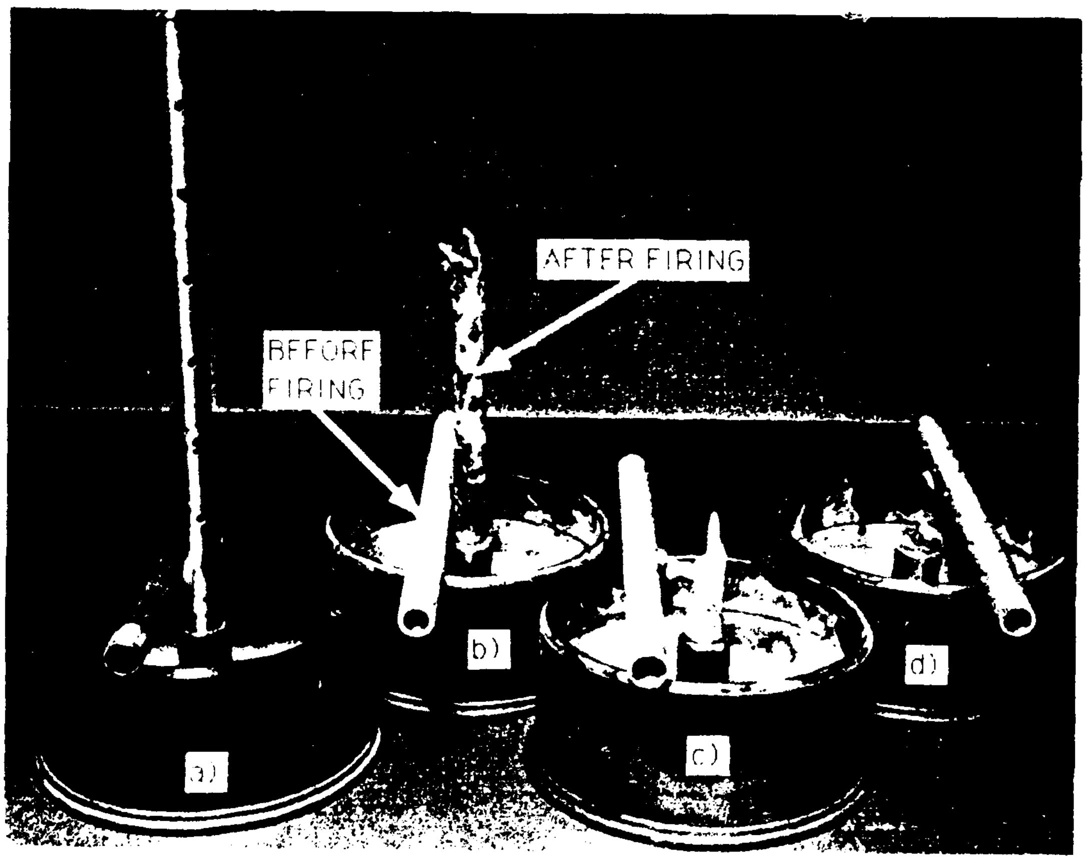

Figure 4. Post-Fired 120-mm DM13 Casings, Consisting of Stub Base With Protruding: a) Steel (Standard), b) Thick-Walled Aluminum, c) Thin-Walled Aluminum and d) Magnesium Igniter Tubes

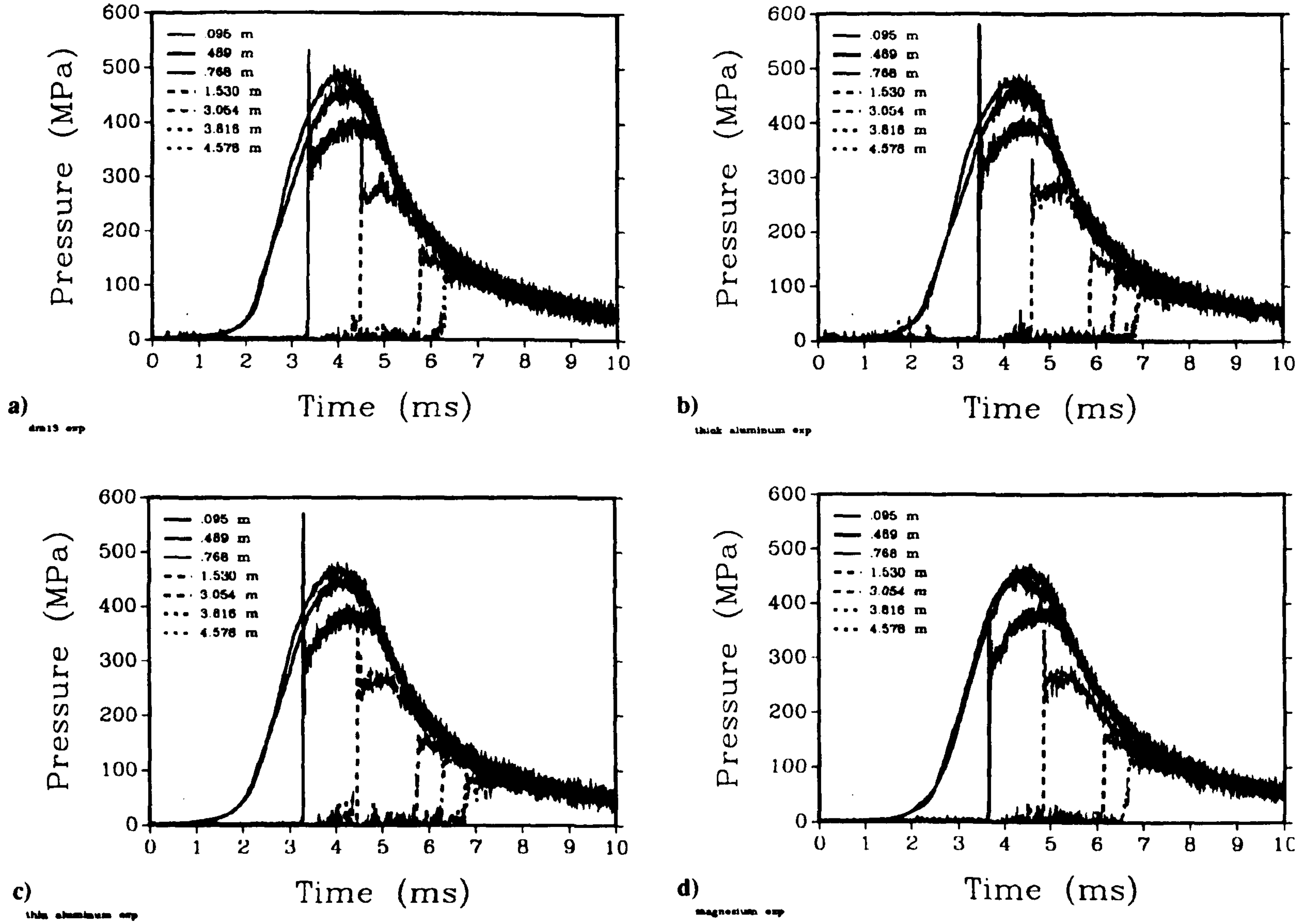

Figure 5. Pressure Versus Time at Various Gauge Locations for a) Steel (Baseline), b) Thick-Walled Aluminum, c) Thin-Walled Aluminum and d) Magnesium Igniter Casing (Note, Zero Time Does Not Correspond to Close of the Firing Key)

curves look very similar and have no large negative values. This would indicate that the modified and unmodified igniters have similar ignition characteristics.

A summary of the maximum breech pressure, muzzle velocity, ignition delay time (defined to be the time from close of firing key to 7 MPa at the breech gage), approximate condition of the igniter casing after firing, and general condition of the gun tube after firing are given in Table 1.

In general, the section of the igniter tube which was threaded into the primer head was not fully oxidized (see Fig. 4). This is probably due (in part) to the heat capacity of the primer head itself, which acts as a heat sink to keep the combustible aluminum or magnesium below its ignition temperature in the thread interface region. In addition, oxidation may not be as complete near the primer end of the tube because of the lower local gas velocity, and hence lower heat transfer, at the closed end of the combustion chamber.

Close inspection of what remained of the aluminum primers indicated that the onset of oxidation probably took place around the vent holes, which is not surprising since not only does the venting of the igniter gas pre-heat the holes, but at the edge of the hole the heat transfer during the main charge combustion is almost two-dimensional. The hole diameters widened significantly during the oxidation process, appearing to burn through to adjacent hole diameters in the thin aluminum case. Thus, hole spacing is an important parameter in the consumption of the igniters.

Table 1. Results of 120-mm Gun Firings

Igniter Casing Material	Maximum Breech Pressure MPa	Muzzle Velocity m/s	Ignition Delay Time ms	Condition of Post-fired Igniter	Particles in Post-Fired Gun
Steel	498	1631	4.7	Whole	------
Thick Aluminum	498	1625	3.8	$\frac{1}{2}$ Consumed	Light Dust
Thin Aluminum	480	1623	9.7	$\frac{9}{10}$ Consumed	Light Dust
Magnesium	476	1617	9.0	Consumed	Porous Black Beads

Having completed the initial tests of a simple (single purpose) combustible casing design, a more complex (dual purpose) casing design was fabricated and tested with the intend of enhancing the durability of the combustible igniter casing - as discussed next.

V. Igniter Casing Durability

Combustible cartridge case side-walls are soft; if a round is accidently dropped, it is conceivable that the propellant bed could shift and thereby transfer a bending moment to

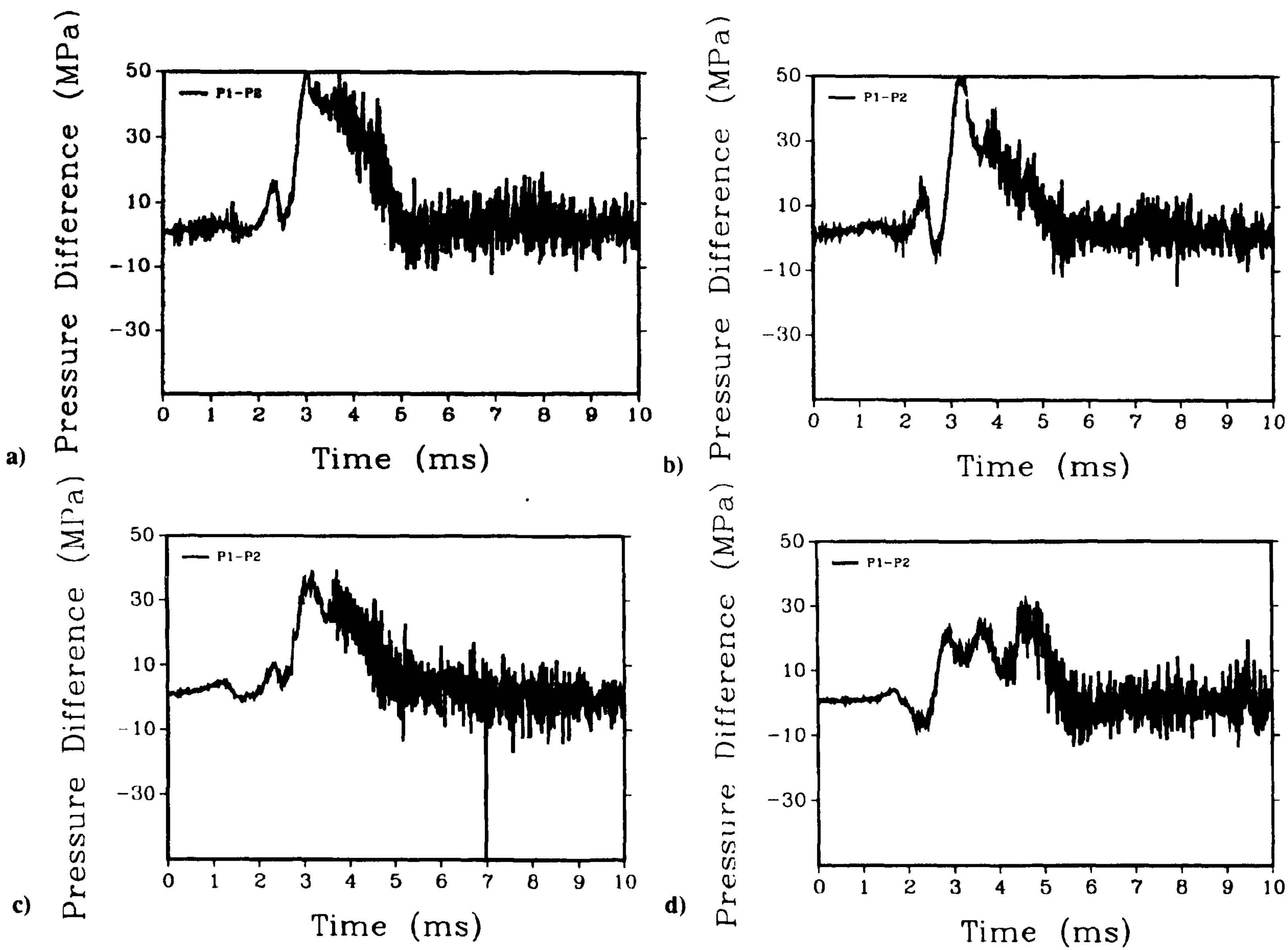

Figure 6. Pressure Difference Versus Time for a) Steel (Baseline), b) Thick-Walled Aluminum, c) Thin-Walled Aluminum and d) Magnesium Igniter Casings (Note, Zero Time Does Not Correspond to Close of the Firing Key)

the igniter. Since aluminum and magnesium igniter casings are weaker than the current steel tube, there is a concern that such a bending moment could break the igniter casing. If this happened, it may lead to poor ignition and potentially dangerous pressure waves.

To address this issue, an attempt was made to create a flexible ignitor-to-primer coupling. Essentially, the primer head was coupled to the combustible (aluminum) igniter casing through a rubber hose. The hose was joined (with an epoxy adhesive) to the primer at one end and to the igniter at the other end. The hose was then encapsulated within an external spring (to enhance the radial and axial stiffness of the joint), see Fig. 7. This primer-igniter assembly was then tested in the manner described above.

Post-firing examination indicated that during firing the spring stretched axially until it broke, which released the combustible igniter casing within the bore. It could not be determined whether the igniter casing was fully consumed within the bore, or whether it followed the projectile out the muzzle: no casing fragments were found inside or outside the gun. Apparently, when the charge inside the igniter began to burn and pressurize the casing, the pressure on the inner wall of the igniter end-cap created a tensile force which stretched the flexible joint until the spring broke and the adhesive bond failed.

This malfunction had a very noticeable effect on the ignition delay time. The normal ignition delay of 2-7 ms for the DM13 round was extended to nearly 90 ms. Presumably, when the igniter separated at the joint the pressure within the casing dropped, as did the intensity of the flame exiting the igniter holes. Such a lowered igniter heat flux might explain why the main propellant charge took a longer time to ignite.

Even though the ignition delay was noticeably affected by the igniter separation, the chamber pressure curves were not: they maintained a smooth variation not unlike that shown for a normal ignition, e.g., Fig. 5a. That is not to say, however, that this type of malfunction would not be a safety problem for cold propellant. In any case, such an extreme ignition delay would not be acceptable from a gun accuracy viewpoint, as the gun pointing angle and target could move appreciably during this ignition delay period.

VI. Unresolved Questions

In addition to the durability issue discussed in the previous section, there remains some other unanswered questions concerning the performance of consumable metallic igniter casings before their use in gun charges can be considered.

Will the metallic igniter casings work as well at temperature extremes as they have at ambient? Testing needs to be performed.

With the aluminum igniter casings the major product of combustion is Al_2O_3, which is an abrasive material. Would the continuous use of aluminum primer casings lead to excessive wear or would the major portions of the Al_2O_3 be carried along with the products of combustion and be swept out the gun? Other than a light dust, there was not any noticeable material detected in the gun tube after firing with the aluminum igniters. The firing with the magnesium igniter casing, however, left a considerable amount of porous, black, bead-like

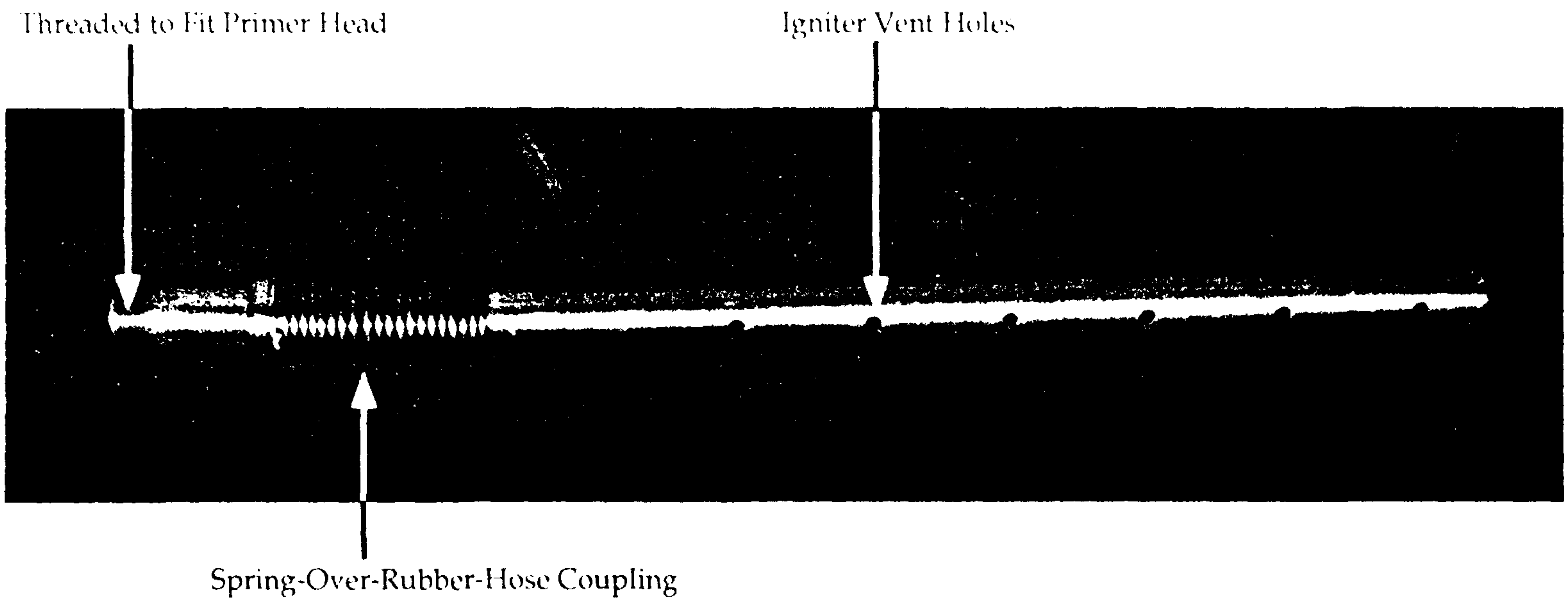

Figure 7. Flexible Igniter-to-Primer Joint Design

material lying along the bottom of the bore; presumably, this was magnesium oxide.

The thin aluminum and magnesium igniter casings had ignition delays twice that of the standard (steel) DM13 casing, while that of the thick aluminum igniter was close to that of the DM13. The FEM prediction of localized weakness, or failure, near the vent holes for both the thin-walled aluminum and the magnesium tubes might explain the longer ignition time for these two cases (as a rupture of the vent hole would tend to diffuse the jet issuing from the hole), but a larger statistical sample needs to be fired.

And finally, the long term storage and chemical compatibility of combustible metallic igniter casings, such as aluminum or magnesium, needs to be determined.

VII. Conclusions

Greater than 90% of aluminum and magnesium igniter casings can be consumed during the ballistic cycle in DM13 charges. The thickness and hole pattern of the igniter casing appear to be important factors in determining the amount of casing material consumed.

The interior ballistics obtained from firing a DM13 with an aluminum or magnesium igniter casing is similar to that obtained from the standard, steel, igniter casing. In particular, the maximum breech pressure and muzzle velocities are nearly the same, as are the pressure-versus-time and pressure-difference-versus-time curves.

Both finite-element and interior ballistics modeling proved useful in evaluating combustible igniter designs and their chance for success prior to fabrication and testing of the actual hardware.

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6. Friedman, R. and Maček, A., "Combustion Studies of Single Aluminum Particles," *9th International Symposium on Combustion*, 1963, pp. 703-712.

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